京都大学	博士（工学）	氏名	Bhogendra　Mishra
論文題目	LAND COVER/USE CHANGE AND CHANGE PATTERN DETECTION USING RADAR AND OPTICAL IMAGES: AN INSTANCE OF URBAN ENVIRONMENT （レーダと光学画像を用いた土地被覆・利用の変化、変化形態の検出：都市環境の事例）		

（論文内容の要旨）

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, it involves the ability to quantify temporal effects using multi-temporal data sets. Because of the availability of the image in a regular interval and consistent image quality, the imageries acquired by the Earth-orbiting satellite are being used for detecting several changes such as land change analysis, urban extension mapping and monitoring, crop monitoring, assessment of deforestation, the study of the seasonal vegetation changes, disaster monitoring, tracking the glacier and snow cover dynamics and other environmental changes etc. The author proposed a method to automatically detect land cover/use change and in addition detect change pattern from radar and optical satellite images.

In the first part of this thesis, the author proposed supervised and unsupervised change detection methodologies focused on the analysis of multi-temporal SAR images. These approaches are based on three main steps: (1) a comparison of multi-temporal image was carried out by the normalized difference ratio (NDR) operator; which is using in this work for the first time in the SAR image and appear to be better than any other change image generation approaches currently in practice, (2) implementing a novel supervised or unsupervised thresholding and (3) generating the change map by coupling of thresholding along with a region growing algorithm. In the first step, the two filtered multi-temporal images were used to generate NDR image that was subjected to analysis. In the second step, by assuming a Gaussian distribution in the no-change area, the author identified the pixel range that fits the Gaussian distribution better than any other range iteratively to detect the no-change area that eventually separates the change areas. In the supervised method, several samples no-change pixels were selected and the mean (μ) and the standard deviation (σ) were obtained. Then, $\mu \pm 3\sigma$ was applied to select the best threshold values. Finally, threshold values obtained in previous step (step 2) was modified and implemented with the coupling of the region growing algorithm to consider the spatial information to generate the change map. The effectiveness of the proposed methods was verified with the simulated images and the real images associated with geographical locations. The results were compared with the manual trial and error procedure (MTEP) and traditional unsupervised expectation-maximization (EM) method. Both proposed methods gave similar results with MTEP and significant improvement in Kappa coefficient in comparison to the traditional EM method in both geographical locations. The coupling of the modified thresholding with the region growing algorithm is very effective with all methods.

With the advancement of the SAR technology, in addition to the single polarized SAR images, dual and (quad) fully-polarized SAR (PolSAR) images are available. The fully PolSAR images allow the generation of several very useful pieces of information and descriptors. These descriptors could supplement the results derived from single polarization images by adding several unique features, reflecting the complex nature of man-made structures that could be sensitive to different types of changes in urban environments. In this part of the study, the author had the opportunity to identify the best pairs of complementary components of these polarimetric descriptors as well. Thus, the objective of this study is twofold: first, to identify the most

effective descriptors for each change type and ascertain the best complementary pairs from the selected polarimetric descriptors; and second, to develop an information fusion approach to use the unique features found in each polarimetric descriptor to obtain a better change map for urban and suburban environments. The effectiveness of each descriptor was assessed through statistical analysis of the sensitivity index in selected areas and through change detection results obtained by using the supervised thresholding method. A good agreement was found between the statistical analysis and the performance of each descriptor. Finally, a polarimetric information fusion method based on the coupling of modified thresholding with a region-growing algorithm was implemented for the identified complementary descriptor pairs. The mapping accuracy, as measured by the Kappa coefficient, was improved by 0.09 (from 0.76 to 0.85) with a significant reduction of false and missing alarm rates compared to single polarimetric SAR images.

While SAR images are very good for change detection, they are not able to delineate the proper shape of the change area. Thus, in order to overcome such limitation, a SAR and optical information fusion approach is used. Several data fusion techniques are available which allow better analysis and interpretation by making use of complementary information obtained from multiple sensors. In this study, a change magnitude image is generated through change vector analysis (CVA) based SAR and optical information fusion and segmented the change no-change area using thresholding. The fusion is motivated to use the complementary information without losing the inherent information that comes from either SAR or optical images for better change detection. Specifically, it is expected to improve the sharpness of the detected feature, or be able to detect the changed features that were otherwise not possible from a single data source. Thus, a SAR and optical data integration framework for change detection and a relationship for automatic change labeling were developed and deployed in this part of the study. It was carried out in three steps: (i) Computation of two indicators from SAR and optical images, namely: normalized difference ratio (NDR) from multi-temporal SAR images and the normalized difference vegetation index difference (NDVI difference) from multi-temporal optical images, (ii) computing the change magnitude image from NDR and NDVI difference and delineating the change area and (iii) the development of an empirical relationship, for automatic change labeling, in between NDR and the NDVI difference while changing a land use/cover feature from one type to another. The experiment was carried out in the outskirts part of Ho Chi Minh City, one of the fastest growing cities in the world. The improvement of the change detection results by making use of the unique information on both sensors, optical and SAR, is also noticeable with a visual inspection and the kappa index was increased by 0.13 (0.75 to 0.88) in comparison to only optical imageries. The empirical relationship between the response of surface feature to optical and SAR imagery has successfully delineated six changed classes in a very complex urban sprawl area that was otherwise impossible with multi-spectral optical imagery.

While summarizing all the works done in this study, change detection from multi-temporal SAR images, PolSAR images and optical and SAR information fusion for automatic change pattern detection was done independently.

氏　名	Bhogendra　Mishra

（論文審査の結果の要旨）

本論文では、近年、衛星搭載型 SAR (Synthetic Aperture Radar: 合成開口レーダ）画像が広く普及し、更なる高度利用が検討されている背景を踏まえて、都市に特化して土地被覆・土地利用変化及びその変化形態を定性的に自動推定する手法を提唱している。

まず、2 時期の SAR 画像を用いた土地被覆・土地利用変化の自動抽出手法の開発においては、後方散乱強度から計算できる NDR (Normalized Difference Ratio) という指標を提案している。比較的簡便な指標ではあるが、従来の単純な比率で表される指標に比べてノイズの影響を緩和でき、適用範囲がより広いことを理論的に示した。提案手法は NDR に対する閾値処理に加えて、空間的な文脈を参照しながら修正を加えることで誤検出、未検出の割合を減らす工夫が施されている。シミュレーション画像だけでなく、大規模開発が行われたベトナム・ホーチミン市周辺の PALSAR 画像を用いて、提案手法の有効性を実証した。

続いて、多偏波 SAR 画像に対し、土地被覆・土地利用変化検出において効果的な偏波データやそれらから計算される指標を定量的に比較した。ホーチミン市周辺の PALSAR 画像に適用して検証した結果、コヒーレンシー行列 T の対角成分である T_{22} と T_{33} を用いた抽出が最も効果的であることを明らかにした。

最後に、2 時期の SAR 画像と光学画像を用いた土地被覆・土地利用変化抽出手法の開発では、両者の変化量を利用することで、可能性の高い土地被覆・土地利用変化パターンを定性的に推定する試みが述べられている。SAR 画像から計算される NDR を用いて地物の消失や出現を推定し、それに加えて光学画像から計算される NDVI (Normalized Difference Vegetation Index) を用いて、構造上は大きな変化が生じない土地被覆・土地利用変化（例えば植生から人工構造物への変化）を捕捉する仕組みを構築した。特に衛星画像を用いて解析する実務者からは、実際にどのような土地被覆・土地利用の変化が発生しているかを推定したいという要望は強く、提案手法はこのような実務上の要望に応えうる可能性を秘めていると言える。

また、平成 26 年 6 月 9 日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。